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AEROMEDICAL IMPLICATIONS OF THE X-CHROM LENS FOR IMPROVING COLO--ETC(U)
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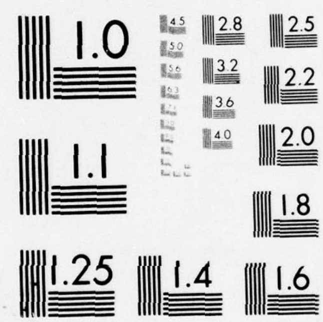

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AEROMEDICAL IMPLICATIONS OF THE X-CHROM LENS FOR IMPROVING COLOR VISION DEFICIENCIES

Kenneth W. Welsh
John A. Vaughan
Paul G. Rasmussen

Civil Aeromedical Institute
Federal Aviation Administration
Oklahoma City, Oklahoma

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16. Abstract

The X-Chrom contact lens is a recent device recommended to improve defective color vision. The red lens is usually worn on the nondominant eye and may require extended wearing for optimum color vision enhancement.

A battery of tests was given to 24 individuals, 12 with normal and 12 with defective color vision. A mix was made between standard clinical color vision tests, spectral signal light tests, and visual/oculomotor performance tests. Between the first and second evaluations (approximately 7 weeks), individuals with defective color vision wore X-Chrom contact lenses for 6 hours each day.

While wearing X-Chrom lenses, subjects had significantly improved scores on standard clinical pseudoisochromatic plate tests, including the Hardy-Rand-Rittler, Ishihara, and Dvorine plates. Our data indicated that color identification scores using the Farnsworth Lantern, Color Threshold Tester, and the Aviation Signal Light Gun were not significantly different for evaluations made with and without the X-Chrom lens. Minimal changes were found on several tests including the Farnsworth D-15, aeronautical chart color identification task, Holmgren Yarn, visual acuity, phorias, and stereoscopic depth perception. The majority of control and experimental subjects noted a change in the perceived path of the swinging pendulum (Pulfrich test) while viewing through a monocular red filter or an X-Chrom lens, respectively.

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AEROMEDICAL IMPLICATIONS OF THE X-CHROM LENS FOR IMPROVING COLOR VISION DEFICIENCIES

I. Introduction.

Operators of aircraft, land vehicles, and watercraft must frequently identify signal light colors for purposes of navigation and collision avoidance. In addition, individuals are frequently required to identify colors created when light waves are reflected selectively from the surface of objects. Tasks of this nature include recognition of color-coded instrument displays, electronic components, and cartographic materials. Accordingly, government agencies frequently require testing of color vision for these individuals and impose operating restrictions when necessary.

Genetic color vision deficiencies occur in approximately 8 percent of males and in less than 1 percent of the female population. The majority of these individuals experience varying degrees of color confusion, especially when colors are desaturated by environmental conditions including shifts in chromaticity or color temperature (11). Several investigators have determined the consequences of defective color vision on recognition of signal light colors (4,9,12) and reflective pigment colors (5).

Schmidt (10) reviews comprehensively past efforts and devices used to improve defective color perception. She describes early attempts of Seebeck in 1837 and Maxwell in 1857 to improve color vision with devices such as chromatic filters, multiple filter systems, light sources, prismatic arrays, and diverse training techniques. The X-Chrom contact lens developed by Zeltzer (14) is a recent addition to devices claimed to improve faulty color perception.

The present investigation was undertaken in response to several inquiries to the Federal Aviation Administration (FAA) concerning certification of individuals wearing X-Chrom lenses. The promising report by Ditmars and Keener (2) lent substance to these queries. Our results include performance scores on selected color vision tests as well as other tasks considered germane to the transportation environment.

II. Methods.

Volunteer subjects were categorized as having normal or defective color vision according to results from the Dvorine and Hardy-Rand-Rittler (HRR) pseudoisochromatic plate tests, the Farnsworth D-15 Panel test, and the Farnsworth Lantern test. Selection was also based on normal findings from a complete ocular examination, including appropriate measurements of all color-defective subjects to assess their ability to wear contact lenses.

The color-defective (experimental) group consisted of 11 males and 1 female with ages ranging from 19 to 56 years (mean 40 yr) while the control group with normal color vision was composed of 10 males and 2 females with ages from 34 to 58 years (mean 47 yr).

The 12 X-Chrom lenses, ordered to individual specifications, were all plano (0.0 D) power with center thicknesses from 0.17 to 0.18 mm. Light transmission measured through the lenses with a Macbeth Densitometer, Model TD-504 (photopic setting), ranged from 25.1 to 26.9 percent (mean 25.7 percent). Figure 1 shows the relative energy distribution curves obtained by using a Gamma Spectroradiometer, Model 2900MR, with and without an X-Chrom lens positioned between the microscope receptor head and a standard luminance source (Spectra, 100 fL).

Following the first battery of tests given to the control and experimental subjects (Evaluation I), the 12 color-defective subjects were given instructions concerning proper care and handling of their X-Chrom lenses. After a prescribed adaptation period and with periodic ophthalmic evaluations, the subjects wore the lenses on their nondominant eyes 6 hours each day for a period of 7 weeks. The same battery of tests was then repeated (Evaluation II) with the experimental subjects wearing their X-Chrom lenses and their spectacle lenses, as required, for distant or near vision. With the exception of the Pulfrich Pendulum test, control subjects were evaluated without a red filter during the second evaluation.

The battery of tests given twice to each subject consisted of the following: (i) six pigment or reflective color identification tests, primarily clinical in nature, (ii)

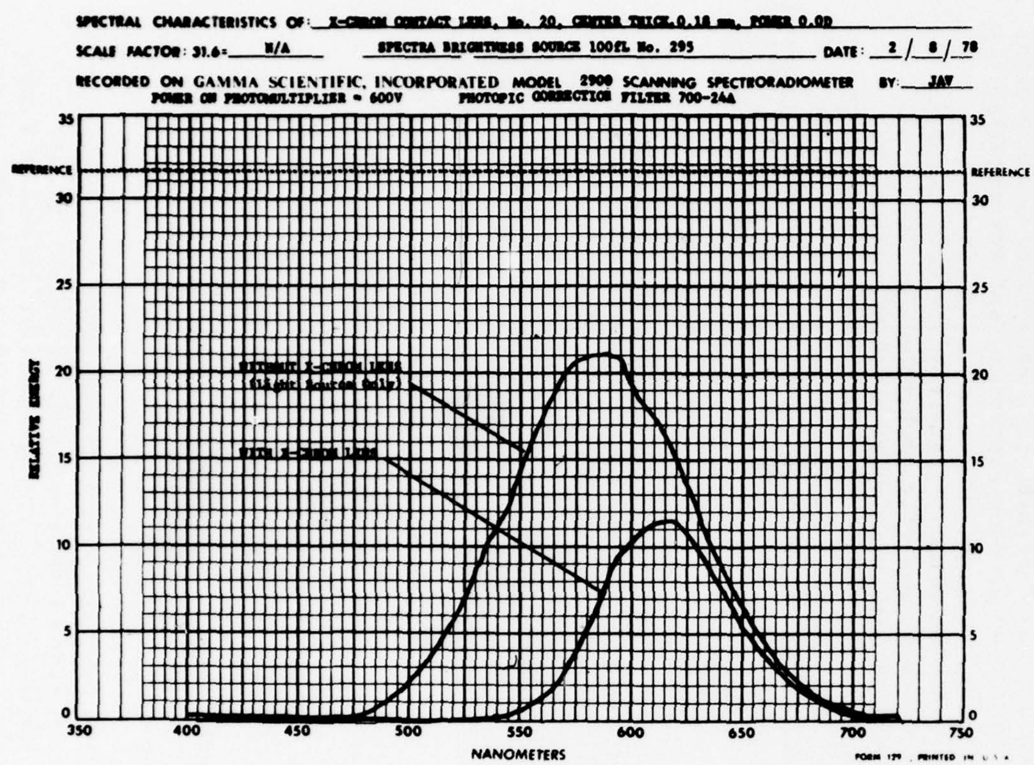

FIGURE 1. Relative spectral energy distribution curves with and without the X-Chrom lens positioned between spectroradiometer and light source.

three signal light color identification tasks, and (iii) five visual/stereoscopic tests. Unless indicated otherwise, tests were administered as specified in the operation manual for each device. Scores on each test were analyzed by using one of two methods described by Kirk (7), Randomized Block Design, pp. 131 and 239, or Split Plot Factorial, pp. 249 and 298.

Scores on pseudoisochromatic plate tests were based on the number of symbols correctly identified for HRR 2d Ed. (1957), plates 3 through 16, Ishihara (1976), plates 2 through 15, and Dvorine 2d Ed. (1953), plates 2 through 15. Plates 16 and 17 of the Ishihara test were used to classify the type of color vision defect. All pigment color vision tests were given under 22-fL daylight blue lighting provided by a Macbeth Easel Lamp.

The Farnsworth Dichotomous D-15 Panel test allows simultaneous comparison of 15 hues from all parts of the spectrum and may therefore reveal hues that are confused by the color-defective individual. Each subject's confusion or crossover lines were plotted on standard scoring sheets according to his or her arrangement of the color samples. An individual's color vision defect was specified when crossovers paralleling one reference line (protan, deutan) outnumbered the others by two or more.

A color vision test developed by the authors was constructed from U.S. Sectional Aeronautical Charts. The subjects were asked to identify the colors of 12 features or symbols printed on selected chart samples. Color features requiring identification included yellow, magenta, blue, and black printed over shades of yellow, brown, and green. In addition, chart background colors depicting various terrain elevations were visually matched to a color-coded reference key printed on the chart.

The modified Holmgren Yarn test consisted of 3 large reference skeins (red, green, and purple) and 25 smaller skeins. The small samples, composed of five different shades of each reference color and five shades each of brown and gray, were scattered randomly on a white tabletop. Each subject was asked to select from the samples skeins that matched the three reference colors. Correct responses and color-confusion errors were recorded.

The first of three signal light tests given to each subject during both evaluations was the Farnsworth Lantern. The instrument was designed to display three signal light colors. The signal colors were presented in pairs with both mixed pairs (red-green, red-white, and green-white) and equal pairs (red-red, green-green, and white-white). Each light was 2.5 mm in diameter and the two lights were separated vertically by 12.0 mm. The light pairs were recessed approximately 2.5 cm (1.0 in) within the body of the lantern. Subjects viewed the lights from a distance of 6 m (20 ft) and 2.4 m (8 ft) under ambient luminance of 100 and 1.0 fL as measured from a white oxide reflectance plaque positioned adjacent to the viewing aperture of the instrument.

Scores on the Color Threshold Tester, Macbeth Corporation, were determined by the number of correct responses to eight spectral colors presented randomly 64 times. Signal light colors included blue, white, yellow, orange, and two shades each of green and red. An eight-step neutral density filter wheel on the front of the device was used to increase illumination of the signal lights after each series of colors was presented. Signal lights were presented singly at a distance of 6 m (20 ft) and with ambient luminance in the target area of 100 and 1.0 fL.

The Aviation Signal Light Gun (ASLG), Type W-1, provided a collimated beam of white, red, or green light 15.2 cm (6.0 in) in diameter, suitable for testing over extended distances. The light gun, located inside a third story window was aimed at the subject standing on the ground 305 m (1,000 ft) and 457 m (1,500 ft) from the building. The subjects looked southward at the light between 1100 and 1500 CDT under sky conditions ranging from clear to moderately overcast. Each color was displayed for 5 s in random order with a 3-min interval between flashes. This procedure followed specifications given in FAA Order No. 8420.8, par. 73k, for medical evaluation of defective color vision. Two additional series of flashes were made at each viewing distance to include: (i) 5-s flashes at 3-min intervals while viewing through neutral-gray sunglasses (American Optical Co., transmission 16.8 percent); and (ii) 5-s flashes presented at 15-s intervals.

Several visual and oculomotor tests were conducted during both evaluation periods. Tests were made with a Bausch and

Lomb Master Ortho-Rater that included: (i) distant visual acuity for right and left eyes, slides No. 71-21-86 and -87, respectively; (ii) lateral and vertical phorias at optical infinity, slides No. 71-21-59 and -60, respectively; and (iii) stereopsis, slide No. 71-21-54.

The Pulfrich Pendulum test was included to assess possible alterations in dynamic spatial perception. The test device consisted of a circular pendulum bob (diameter 6.8 cm (2.7 in)) painted flat white and suspended from a ball bearing pivot by a 63.5-cm (25-in) black metal rod. A circular white fixation target (diameter 3.4 cm (1.3 in)) held in position by a horizontal support rod was located 9.0 cm (3.5 in) below the center of the bob when the pendulum was motionless. Several fluorescent luminaries covered by diffusing panels rendered the display generally shadow-free against a black felt background screen and provided illumination of 50 fc in the target area. Subjects seated 3 m (10 ft) from and at eye level to the pendulum bob were instructed to gaze at the fixation target with both eyes while the bob was put into motion for 30 s. During Evaluation I, subjects viewed the pendulum using only their clear spectacle lenses, as required. During Evaluation II, control subjects observed the display through a red filter held over one eye while the experimental subjects used their monocular X-Chrom lenses. Responses concerning the perceived path of the swinging bob were classified as: (i) straight, side to side; (ii) elliptical, clockwise; or (iii) elliptical, counterclockwise.

Shown in Table 1 for all experimental subjects are the results of five tests that were used to define color vision defects by type and severity. Three of the tests have been described previously. The fourth test, the Farnsworth-Munsell 100 Hue test, measured incremental hue discrimination within four approximately equal portions of the color spectrum. Caps comprising hues from each spectral region were presented in groups and errors were plotted on standard scoring sheets. Interpretation of each subject's defect was made according to recommendations in the test manual.

The Schmidt-Haensch anomaloscope was also used to define each subject's color vision defect. The instrument has two control knobs; the first determines the ratio (mixture) of red to green light in the upper half of the optical field and the second controls the brightness of the lower pure yellow

TABLE 1. Results of Several Tests Used to Define Color Vision Defects of Experimental Subjects

	Pigment Tests				Anomaloscope		
Subj. No.	HRR	Ishihara	D-15	D-100	Type	Notation	Range
13	D_M	D	D	D	D	23/16	6 - 30
14	D_M	D	D	D	X	30/17	0 - 73
15	P_M	X	P	P	X	37/17	0 - 73
16	D_W	D	X	D	D	18/17	7 - 19
17	X_S	D	D	D	X	25/17	0 - 73
18	X_M	D	X	D	D	12/20	0 - 23
19	D_M	D	N	D	D	21/18	10 - 22
20	D_W	D	X	D	D	22/16	0 - 31
21	D_M	D	D	D	X	19/19	0 - 73
22	X_M	X	P	X	X	21/19	0 - 73
23	N	D	N	X	D	37/17	11 - 45
24	X_M	D	N	D	D	19/17	0 - 31

Key: D = Deutan P = Protan

X = Unidentified N = Normal

S = Strong M = Medium W = Weak

field. Settings of the red/green mixture control (upper field) can range from 0 to 73 with 0 being pure green light and 73 pure red light. Subjects are required to adjust both knobs to create an optimum match between upper and lower fields (Rayleigh Notation). The numerator and denominator of the Rayleigh Notation represent, respectively, the setting of the red/green mixture control and the yellow brightness control. Ratios that typify normal color vision are settings in the low forties over settings in the high teens. Individuals with deuteranomalous defects require more green or less red to match pure yellow resulting in lower numerator values, whereas protanomalous types will adjust the red/green control to higher (more red) values.

The severity of the color vision defect is indicated by the range of the red/green control that can be matched by the pure yellow field. During this procedure, the experimenter varies the red/green mixture while the subject attempts to match each setting with the brightness control of the yellow field. Normal color vision is characterized by a narrow range centered around the normal red/green mixture setting, i.e., 42. Expanded ranges with a general shift toward either end of the red/green scale indicate the type of defect. Severe color vision defects are indicated by a range extending from 0 to 73. In other words, all ratios of red to green light, including pure green and red, can be matched by the yellow field. Protanopes are identified by their tendency to reduce the brightness of the pure yellow field to match spectral reds.

The average Rayleigh Notation for all control subjects was numerator 41.5, S.D. $\pm$ 1.4, and denominator 17.0, S.D. $\pm$ 1.2. For the control group, the mean range at the low end is 38.7, S.D. $\pm$ 2.0 and for the high end is 43.6, S.D. $\pm$ 1.9. From these data in Table 1, three X-Chrom subjects (Nos. 15, 22, and 23) were classified as having protanopic or undefined color vision defects; the remaining nine were classified as having well-defined deuteranopic defects.

III. Results.

Scores on the three pseudoisochromatic plate tests were analyzed for all 12 X-Chrom subjects and again for the 9 X-Chrom subjects determined to have well-defined deuteranopic defects. Correct identification scores increased significantly ($P \leq 0.01$) between the first and second evaluations for each

of the three tests and for both subject groups (Table 2). Subjects with normal color vision had no errors on the pseudoisochromatic plate tests.

The three plate tests noted above are approved for use by FAA Aviation Medical Examiners. Minimum passing scores specified in the FAA Guide for Aviation Medical Examiners for plate tests differ between Class I and Classes II and III examinations. Data show that for Class I medical certificates, none of the color-defective subjects passed minimum requirements for the three plate tests without their X-Chrom lenses. With X-Chrom lenses, no experimental subjects passed minimum requirements for HRR plates while three and seven subjects passed with Dvorine and Ishihara plates, respectively. For Classes II and III certificates, no experimental subjects without their X-Chrom lenses passed the Ishihara plate test while three and five subjects passed the HRR and Dvorine plates, respectively. Wearing their lenses, 8 subjects passed the HRR plates, 11 passed with Ishihara, and 12 passed with Dvorine plates.

Mean scores obtained with the Farnsworth Lantern were not significantly different between use and nonuse of the X-Chrom lens for either viewing distance or lighting condition (Table 3). Significant differences occurred between luminance level for both evaluations at 6 m (20 ft) with improved scores ($P \leq 0.01$) under dim ambient illumination. Significant differences ($P \leq 0.01$) in performance also occurred between subjects within the experimental group and between experimental and control groups under all viewing conditions, with the control group making no errors on the Farnsworth Lantern test.

Mean correct scores for the Color Threshold Tester were not significantly different with or without the lens under bright or dim illumination (Table 4). Significant differences ($P \leq 0.01$) were again found between luminance conditions (better performance under dim lighting) and between the experimental and control groups. There were no significant first order interactions between evaluations and luminance conditions.

Minimum requirements specified in the FAA Guide for Aviation Medical Examiners for the approved lantern tests remain the same for all classes of medical certificates. Data indicate that none of the experimental subjects passed minimum requirements for the Farnsworth Lantern test with or without their

TABLE 2. Average Number of Plates Correctly Identified Per Subject and Range for Subject Groups on Three Pseudoisochromatic Plate Tests. HRR Scores Based on 24 Symbols on 14 Plates.

Test	Total Plates-Symbols	Evaluation I		Evaluation II	
		All Color Defectives	Deutans Only	All Color Defectives	Deutans Only
Ishihara	14	2.1 (2-3)	2.0 (2-2)	10.1 (4-14)	10.3 (7-14)
Dvorine	14	1.4 (0-4)	1.3 (0-4)	8.3 (4-13)	7.8 (4-11)
HRR	24	10.5 (5-21)	9.8 (5-19)	17.2 (12-21)	17.0 (13-21)

TABLE 3. Average Number of Light Pairs Correctly Identified and Range for Subject Groups for Farnsworth Lantern Test (Light Pairs Presented 18 Times Each Condition).

Subjects	Distance	Luminance	Means and Ranges of Correct Responses: Eval. I	Eval. II
All Color Defectives	6 m	Bright	5.6 (0-11)	4.9 (0-10)
		Dim	8.3 (2-18)	7.8 (2-18)
	2.4 m	Bright	7.4 (2-12)	6.1 (2-12)
		Dim	7.5 (1-18)	8.3 (2-18)
Deutans Only	6 m	Bright	5.6 (0-11)	4.2 (0-10)
		Dim	8.1 (2-16)	8.0 (2-18)
	2.4 m	Bright	7.7 (4-12)	5.6 (2-9)
		Dim	7.4 (1-18)	8.6 (2-18)

X-Chrom lenses. With the Color Threshold Tester, one subject (No. 19) passed without an X-Chrom lens while one subject (No. 16) passed with the lens. Table 5 shows the number of experimental subjects passing minimum requirements without and with X-Chrom lenses for each of five tests approved for use by the Aviation Medical Examiners.

Shown in Table 6 for the Aviation Signal Light Gun test are the number of experimental subjects with any color identification errors and their average number of errors for each of eight viewing conditions. During each condition, subjects attempted to identify all signal light colors (red, green, and white) presented once in random order. On Evaluation I, four experimental subjects (16, 19, 21, and 23) had perfect scores (12 correct) for all colors presented at 3-min and 15-s intervals. During Evaluation II, four subjects wearing their X-Chrom lenses had perfect scores (subjects 14, 19, 23, and 24). Subjects 19 and 23 therefore

TABLE 4. Average Number of Lights Correctly Identified and Range for Subject Groups for Color Threshold Tester (Light Presented 64 Times Each Condition)

		Means and Ranges of Correct Responses	
Subjects	Luminance	Eval. I	Eval. II
Controls	Bright	36.7 (27-49)	35.7 (26-43)
	Dim	60.4 (54-61)	59.0 (57-62)
All Color Defectives	Bright	16.2 (6-30)	14.2 (3-22)
	Dim	33.2 (15-51)	32.5 (19-51)
Deutans Only	Bright	17.5 (6-30)	14.6 (3-22)
	Dim	34.5 (15-51)	32.7 (19-51)

TABLE 5. Number of Experimental Subjects Obtaining Passing Scores Without and With the X-Chrom Lens

	Class I		Class II and III	
Test	Without	With	Without	With
HRR	0	0	3	8
Ishihara	0	7	0	11
Dvorine	0	3	5	12
Farnsworth Lantern	0	0	Requirements same as Class I	
CTT Lantern	1	1		

TABLE 6. Number of Experimental Subjects With Any Errors and Their Average Number of Errors (In Parentheses) on Aviation Signal Light Gun Test

		Subject Errors	
Time Between Flashes	Distance	Evaluation I	Evaluation II
3 min	305 m (1,000 ft)	3 (1.3)	4 (1.2)
	457 m (1,500 ft)	4 (1.0)	6 (1.2)
15 s	305 m (1,000 ft)	3 (1.0)	1 (2.0)
	457 m (1,500 ft)	6 (1.0)	5 (1.2)

had perfect scores on both evaluations. On Evaluation II, three X-Chrom subjects (15, 16, and 21) made more errors (mean 2.3), three subjects (14, 22, and 24) made fewer errors (mean 1.3), and the four remaining subjects had the same number of errors as in Evaluation I. During Evaluation I, a total of eight errors were made when the ASLG was flashed at 3-min intervals while nine errors were made when the light was flashed at 15-s intervals. Control subjects made no color identification errors under all viewing conditions. Subjects also responded to the ASLG while wearing neutral-gray sunglasses. Total errors for all experimental subjects on Evaluation I were 17 without and 16 with sunglasses. For Evaluation II, X-Chrom wearers made a total of 20 errors without and 13 errors while wearing sunglasses.

The numbers of crossover (color confusion) errors made on the Farnsworth D-15 test were not significantly different between Evaluations I and II. Deutans had 5.3 and 3.7 crossovers while all defective subjects (including deutans) had 5.2 and 4.3 for first and second evaluations, respectively.

Results of the modified version of the Holmgren Yarn test indicate no significant difference between the first and second evaluations in ability to match sample skeins to three primary colors while wearing the X-Chrom lens. Results are shown in Table 7 for all X-Chrom subjects and for the deutans within the X-Chrom group. Correct matching scores, however, differed significantly ($P \leq 0.01$) between the three primary colors with performance consistently lowest for shades of green and best for shades of purple.

Scores on the aeronautical chart color identification task developed by the authors were not significantly different between the first and second evaluations. Mean correct scores for all experimental subjects were 80.5 and 81.2 percent for first and second evaluations, respectively. Comparable scores for the nine deutans were 85.2 and 82.4 percent. Individual scores ranged from 33 to 100 percent correct for Evaluation I, and from 58 to 100 percent for Evaluation II. Five subjects showed improved scores on Evaluation II while six registered decreased scores.

The 12 control subjects with normal color vision made no errors on the Farnsworth D-15 test, Holmgren Yarn test, and aeronautical chart color identification task.

Analysis of variance indicated no significant differences in visual acuity between subject categories (control and X-Chrom), Evaluations I and II, and right and left eyes. There was a first order interaction ($P \leq 0.05$) when analyzed for subject category by right and left eyes. Here visual acuity decreased in the X-Chrom eye (7 of 12 subjects) from a mean of 20/18.3 to 20/20.6. These differences, although not specifically evaluated, may result from induced chromatic aberration and/or reduced light intensity by the X-Chrom lenses.

Differences in lateral phoria, vertical phoria, and stereopsis as measured with the Bausch and Lomb Ortho-Rater, were not significant between subject groups, between first and second evaluations, or for first order interactions (subject groups by evaluations).

Results of the Pulfrich test for the 12 control and 12 experimental subjects are given in Table 8. On Evaluation II, net changes from a given perceived path of swing (straight or elliptical) to a different path occurred for nine of the control and nine of the experimental subjects. On Evaluation II, control subjects were also tested without a red filter. Under these conditions (normal binocular viewing), only two subjects reported a change from their responses on Evaluation I.

IV. Discussion.

Pseudoisochromatic plate tests are commonly used to determine the presence of color vision defects. They are used less often to establish the type or degree of an individual's deficiency. Performance on plate tests (pigment/reflective tests) is based primarily on: the individual's color vision status; the hue and saturation of the test symbol and background; the type and amount of illumination; and the available viewing time. An article by Birch (1) describes methods used to select printing inks necessary to effectively evaluate various types of anomalous color perception.

Ditmars and Keener (2) have investigated the effectiveness of the X-Chrom lens to improve scores on three pseudoisochromatic plate tests. Using 10 color-defective subjects (5 wearing X-Chrom lenses, 5 viewing through red filters), they found improved scores ranging from 13 to 43 percent (mean 34.6 percent)

TABLE 7. Mean Scores (Percent Correct) for Experimental Subjects on Modified Holmgren Test

Primary Colors	Evaluation I: All Defectives	Evaluation I: Only Deutans	Evaluation II: All Defectives	Evaluation II: Only Deutans
Green	68.3	75.6	73.3	75.6
Purple	90.0	93.3	91.7	97.8
Red	80.0	82.2	81.7	80.0

TABLE 8. Distribution of Responses of the Pulfrich Test

Subject	Individual Responses: Evaluation I	Individual Responses: Evaluation II
Control	10 Straight	7 Elliptical 3 Straight
	2 Elliptical	1 Straight 1 Reversed Elliptical
Experimental	11 Straight	8 Elliptical 3 Straight
	1 Elliptical	1 Reversed Elliptical

with the American Optical Co. 14-plate test, 43 to 79 percent (mean 61.1 percent) on the Dvorine plates, and 0 to 80 percent (mean 49.6 percent) for the HRR plates. The authors did not specify the duration of lens wear between first and second evaluations.

LaBissoniere (8) compared performance on two pseudoisochromatic plate tests with subjects wearing X-Chrom lenses and spectacle-mounted red filters. All nine subjects with defective color vision had improved scores on the Ishihara plates with either device, while no improvements were found on the HRR plates.

Results of our investigation suggested significant improvements by all X-Chrom subjects for the Ishihara, Dvorine, and HRR pseudoisochromatic plate tests. Results for Evaluation II indicate that all X-Chrom subjects met minimum color vision requirements for Classes II and III medical certificates specified for Dvorine plates and the majority of subjects met these requirements for Ishihara and HRR plates.

Zeltzer (14) describes color interpretation with the X-Chrom lens as that of retinal rivalry; the eye without the lens receives unaltered wavelengths which are obscured in the filtered eye. Heath (5) suggests that perception of hues with the X-Chrom lens is based on learned discrimination of binocular luster that varies in amount with different hues. In our opinion, performance scores on pseudoisochromatic plates are enhanced by a monocular process mediated primarily through the filtered eye. Dot matrices that comprise the test symbol and background are altered differentially in brightness according to the transmission characteristics of the red filter. Recognition of the test symbol then becomes a task of intensity discrimination rather than a chromaticity differentiation task. Binocular interactions occurring to enhance perception of test symbols remain, in our opinion, speculative as evidenced by the following observation. Several subjects wearing X-Chrom lenses on their nondominant eyes were asked to compare the distinctness of pseudoisochromatic symbols with and without the dominant eye covered. Results indicated that most plate symbols were more easily identified with the dominant eye covered than with binocular viewing.

Results of other clinical color vision tests conducted with X-Chrom lenses indicated generally mixed results. Performance scores on the Holmgren Yarn test were reported to have improved by 43 percent in the study by Ditmars and Keener (2). Our data for a 25-skein Holmgren test indicated that scores decreased or remained unchanged for the majority of subjects wearing X-Chrom lenses. LaBissoniere (8) reported that total error scores on the Farnsworth-Munsell 100 Hue test increased by 50 percent for all six deuteranomalous subjects wearing an X-Chrom lens.

Several clinical lantern tests are being used to determine qualifications of vehicle operators and workers in various fields. Our results using the Farnsworth Lantern and Color Threshold Tester showed that scores decreased or remained unchanged for approximately half the X-Chrom lens wearers under each viewing condition.

Our data also indicate that color identification by using the Aviation Signal Light Gun test was not significantly different for evaluations made with and without the X-Chrom lens. However, improved scores were difficult to discriminate statistically because results were generally good without the lens. When performance was evaluated under pass/fail criteria specified in the FAA Order 8420.8, par. 73k, use of the signal light gun would result in failure (any errors at 305 m and 457 m) of 42 percent of the experimental subjects without the lens and 58 percent with the X-Chrom lens. In addition, Steen *et al*. (12), evaluating 137 subjects with defective color vision, suggested that caution should be used when clinical lantern tests and pseudoisochromatic plates are used to predict performance with the Aviation Signal Light Gun test.

Another investigator (8) wearing an X-Chrom lens noted that under nighttime viewing, red and amber traffic lights were more difficult to differentiate with the lens than without it. He explained that the brightness of the red light was enhanced by the lens thereby diminishing the brightness difference between red and amber signal lights.

Finally, alterations noted previously in the Pulfrich test remain, in our opinion, speculative with respect to operator performance and beyond the scope of this investigation. For example, aberrations in the perceived path of the swinging

pendulum are a normal response when viewing through a monocular filter (6,13) or with reduced acuity in one eye (3). In our opinion, however, alterations in spatial perception, like those noted for signal light colors, should not be ignored until further data including in-flight evaluations suggest otherwise.

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